IN THE SPECIFICATION

Please amend paragraph **[0033]** as follows:

[0033] Detector 18 digitally captures the focused electromagnetic radiation of wavefront 15. A digital image processor 20 post-processes data 19 from detector 18 to "undo" certain effects induced by optical phase filter 14, to obtain the desired imaging properties (e.g., to increase in the depth of field of ~~imaging~~ system 10, to decrease in wavelength sensitivity, to change aliasing effects, and/or to change tolerance of optics 16 to misfocus-related aberrations). To "undo" the certain effects, digital image processor 20 removes the spatial blur generated by ~~aspheric~~ phase filter 14; at the same time, optics 16 and phase filter 14 operate to ensure that the spatial effects are substantially constant over the range corresponding to the desired imaging properties. Image processor 20 effectively performs a reverse convolution with the spatial blur generated by phase filter 14, utilizing other system parameters as needed and desired to change or enhance the imaging properties. System 10 thus produces a final image 22 with these desired image properties (e.g., a clear image over a selected depth of focus) as described in more detail below.

Please amend paragraph **[0034]** as follows:

[0034] ~~Wavefront coding element~~<u>Phase filter</u> 14 is positioned, rotated and/or translated within optical system 10 by a motor and controller 30 to effect desired phase modification of wavefront 15. Through feedback 32 with motor and controller 30, digital image processor 20 has positional information of optical phase filter 14; this information is utilized within digital image processor 20 to "undo" the spatial effects induced by optical phase filter 14 on the image formed at the detector 18.

Please amend paragraph **[0035]** as follows:

[0035] In one embodiment, optical phase filter 14 is at an aperture of optical imaging system 10 (or at an image of the aperture), such that the point spread function (PSF) of system 10 is substantially insensitive to misfocus and such that the optical transfer function (OTF) of system 10 has no zero-value regions within ~~the~~<u>a</u> passband of detector 18. Because the OTF is devoid of zero value regions, digital image processor 20 may obtain final image 22 by undoing the spatial effects of

optical phase filter 14. Since the OTF is insensitive to misfocus, digital image processor 20 generates final image 22 with the desired imaging properties. U.S. Patent No. 5,748,371 describes wavefront coding to extend depth of field and is incorporated herein by reference.

Please amend paragraph **[0036]** as follows:

[0036] Through operation of motor and controller 30, optical phase filter 14 may also be positioned within system 10 at a principal plane (or image of the principal plane), at an aperture stop (or image of the aperture stop), and/or at a lens (e.g., with optics 16). Such positioning ensures that ~~imaging~~ system 10 minimizes vignetting. In one embodiment, optical phase filter 14 modifies only phase of the wavefront between object 12 and detector ~~16~~18 so as to minimize energy losses within system 10. Those skilled in the art appreciate that filter 14 may be incorporated with optics 16 (e.g., as a wavefront encoded surface of an optical element representing optics 16).

Please amend paragraph **[0042]** of the specification as follows:

[0042] In yet another embodiment, two phase filters 14F(1), 14F(2) are shown along optical axis 17 in FIG. 2F. In this configuration, motor and controller 30 may move one or both of filters 14F along direction 48 to vary the combined wavefront phase caused by filters 14F. In another embodiment, motor and controller 30 operate to tilt (e.g., along ~~direction 49~~directions 49(1), 49(2)) one or both of filters 14F to provide desired phase change through the pair of filters 14F, thereby "encoding" wavefront 15 in a way so as to achieve the desired image properties.

Please amend paragraph **[0045]** of the specification as follows:

[0045] For example, the phase function P (equivalent to surface height) of filter 14C(1) and 14C(2) may for example take the phase form of Equation 1:

P(r,~~theta~~θ) = A(r)*Sum[a_i cos(w_i ~~theta~~θ + ~~phi~~ϕ_i)] + B(r)

(Eq. 1)

where r denotes the filter radius value and ~~theta~~θ denotes the filter angular coordinate. The summation (sum, or Σ) is over the index i and A(r) is a function of r multiplied by a function that is a sum of cosine terms. The composite phase modification of wavefront 15 passing through both filters 14C(1), 14C(2) is then

shown in Equation 2, that is motor and controller 30 adjusts phase of wavefront 15 according to rotational movement of filter 14C(1) and 14C(2) about optical axis 17. In particular, assume for example that only one term of the cosine summation is used. If ~~delta~~Δ is zero, filters 14C(1), 14C(2) are perfectly aligned. Motor and controller 30 thus operates to rotate filters 14C(1), 14C(2) as a function of ~~delta~~Δ. With equal and opposite rotations (plus and minus ~~delta~~Δ, respectively) of filters 14C(1), 14C(2), the combined phase becomes:

P_c(r,~~theta~~θ) = {Phase of filter 14C(1) with rotation of (+~~delta~~Δ) } +
{ Phase of filter 14C(2) with rotation of (–~~delta~~Δ) }
= { A(r)* cos(w*~~theta~~θ + ~~delta~~Δ) + B(r) } +
{ A(r,~~theta~~θ)* cos(w*~~theta~~θ - ~~delta~~Δ) + B(r) }
= A(r) [cos(w*~~theta~~θ + ~~delta~~Δ) + cos(w*~~theta~~θ – ~~delta~~Δ)] + 2*B(r)
= 2*cos(~~delta~~Δ) A(r) cos(w*~~theta~~θ) + 2*B(r) (Eq. 2)

Please amend paragraph **[0046]** of the specification as follows:

[0046] Accordingly, the combined phase (e.g., affecting the amount of variation within the depth of field) is modulated by different rotations 46 by motor and controller 30, affecting ~~delta~~Δ through the term cos(~~delta~~Δ) of Eq. 2. For rotation values where ~~delta~~Δ = 90 degrees, the combined phase of the non-rotationally symmetric term can be reduced to zero. At this value of ~~delta~~Δ, the wavefront is minimally modified and the amount of extended depth of field, aberration tolerance, anti-aliasing, etc., is also minimized. For rotation values of ~~delta~~Δ that are multiples of 360 degrees, the combined phase of the non-rotationally symmetric term is maximized; at these values of ~~delta~~Δ, the amount of extended depth of field, aberration tolerance, and anti-aliasing are also maximized. The rotationally symmetric component B(r) is unchanged in form, and is optional. The cosine terms can be replaced by sums of cosines and hyperbolic functions with equivalent result.

Please amend paragraph **[0047]** of the specification as follows:

[0047] A side view of filters 14C(1), 14C(2) is shown in FIG. 2G. FIG. 2G is shown to illustrate that in the above example of Equation 2, the phase form (Eq. 1) of filters 14C occurs on ~~the~~a first side ~~21~~21(1) of ~~each~~phase filter ~~14~~14C(1) and on

<u>a first side 21(2) of phase filter 14C(2)</u>, each facing upstream from detector 18, as shown.

Please amend paragraph **[0048]** of the specification as follows:

[0048] In another example, the phase function P (equivalent to surface height) of filters 14E(1), 14E(2) may for example take the following form:

$P(x,y) =$ ~~alpha~~$\underline{\alpha}$ $\{ x^4 + y^4 \}$ (Eq. 3).

where x and y are Cartesian coordinates of the phase function on filters 14E. The phase of wavefront 15 is encoded by passing through the pair of filters 14E according to translational movements ~~delta~~$\underline{\Delta}$ 44E(1), ~~delta~~$\underline{\Delta}$ 44E(2), respectively, of filters 14E. Motor and controller 30 controls the transverse motion ~~delta~~$\underline{\Delta}$ 44E(1), 44E(2) along the x=y direction (along a 45 deg. angle), to selectively adjust the phase modification of wavefront 15. With motion along the x=y direction, for example, the wavefront phase is altered in both the x and y directions as a function of motion ~~delta~~$\underline{\Delta}$ 44E (equal but opposite motions ~~delta~~$\underline{\Delta}$ 44E(1) and 44E(2) occurring simultaneously). The combined phase implemented by the collection of filters 14E(1) and 14E(2) is then:

$P_c(x,y)$ = {Phase of filter 14E(1) with translation of (+~~delta~~$\underline{\Delta}$) } –
{ Phase of filter 14E(2) with translation of (–~~delta~~$\underline{\Delta}$) }

= ~~alpha~~$\underline{\alpha}$$\{ (x -$ ~~delta~~$\underline{\Delta})^4 + (y -$ ~~delta~~$\underline{\Delta})^4 \}$ - ~~alpha~~$\underline{\alpha}$$\{ (x +$ ~~delta~~$\underline{\Delta})^4 + (y +$ ~~delta~~$\underline{\Delta})^4 \}$

= - 8 ~~alpha~~$\underline{\alpha}$ { ~~delta~~$\underline{\Delta}$ $* (x^3 + y^3)$ + ~~delta~~$\underline{\Delta}^3 * (x + y)$ } (Eq. 4)--

Please amend paragraph **[0049]** of the specification as follows:

[0049] The phase of filter 14E(2) is the negative of the phase of filter 14E(1) in this example. Accordingly, by moving filters 14E(1), 14E(2) in equal but opposite directions, one provides positive phase change and one provides negative phase change. Notice that in this example phase form of the combined filters is a scaled cubic form (~~delta~~$\underline{\Delta}$ $* (x^3 + y^3)$) and a linear phase component (~~delta~~$\underline{\Delta}^3 * (x + y)$). By changing the translation ~~delta~~$\underline{\Delta}$ 44E (i.e., controlled by motor and controller 30 along a line of x, y), the amount of cubic phase (and a corresponding amount of desired imaging property, e.g., depth of field) can be varied. This translation also brings with it a linear phase, prism-like optical axis or image origin translation. So, in

eq. 4, the first term is like a separable cubic and the second term is linear term similar to a prism effect (or tilt). The translation can be used as is, or the mechanism that translates the component parts can be such that the component parts physically tilt away from optical axis 17 (see FIG. 2F) with translation to the complement of the linear phase; more terms may be added to the optical surfaces to purposely remove tilt.

Please amend paragraph **[0053]** of the specification as follows:

[0053] In one embodiment, motor and controller 30 also controls ~~the~~an aperture of system 10. By way of example, system 10 may include an electronically-controllable aperture 31 which responds to motor and controller 30 to adjust the aperture of system 10. When aperture 31 is adjusted, therefore, the depth of field (or depth of focus) changes. Accordingly, motor and controller 30 may additionally move phase filter 14 to adjust the depth of focus (or depth of field) so as to maintain constant image properties irrespective of the change of aperture 31, if desired. In a similar way, aberration tolerance and/or aliasing properties of system 10 may be adjusted to compensate for aperture variation. Digital image processor 20 may also utilize the aperture size information during processing by virtue of feedback 32.

Please amend paragraph **[0059]** of the specification as follows:

[0059] FIG. 4 shows an optical imaging system 100' with a post processor 112, for example a digital filter, that performs post-processing on the image detected by detector 108 to form a final image 114. Post processor 112 removes certain effects of wavefront coding induced by filters 102, 104 to form final image 114, for example to provide a sharp and in-focus image. Optical system 100' is thus particularly well suited for use in digital imaging systems, such as digital cameras, because of the linear response of detector 108 in the form of a digital detector.

Please amend paragraph **[0060]** of the specification as follows:

[0060] Rotation of filters 102, 104 (e.g., each moving as in direction 46, FIG. 2C) may occur through operation of a motor and controller 116'; motor and controller 116' may operate automatically or in response to user commands. Those skilled in the art appreciate that filters 102, 104 may instead be manually adjusted and/or rotated. In one embodiment, initial manual adjustment occurs during assembly

of optical system 100', and further operational adjustment occurs by operation of motor and controller 116', providing a large range of phase modification for wavefront 101.

Please amend paragraph **[0061]** of the specification as follows:

[0061] Optical system 100' may also allow for selective control of focusing, magnitude of the depth of field, and/or aberration reduction. More particularly, FIG. 5 shows one housing 118 that may encase components of system 100'. A user interface 120 mounts with housing 118, as shown. User interface 120 is in electrical communication with a controller 122 (e.g., a microprocessor) to control operation of motor and controller 116', in response to user commands at interface 120, so as to control positioning of filters 102, 104 (to effect phase modification of wavefront 101). Those skilled in the art appreciate that controller 122 may be part of motor and controller 116' as a matter of design choice. In one embodiment, controller 122 receives information 117 from post processor 112, the information for example detailing presence of misfocus and/or aberrations in final image 114. In one example, information 117 is used by controller 122 to direct motor and controller 116' to move filters 102, 104 and modify phase of wavefront 101, such as to control depth of field and aberration tolerance within system 100'. This control then adjusts the image quality of final image 114.

Please amend paragraph **[0062]** of the specification as follows:

[0062] FIG. 6 shows one process 200 facilitating operation of optical system 100', FIG. 5. In step 202, a user makes selections on user interface 120 regarding desired focusing, degree of depth of field, amount of anti-aliasing and/or aberration reduction within system 100'. In response to user selection, a signal is generated and communicated to controller 122. In step 204, controller 122 generates a command signal for communication to the motor and controller 116'. Motor and controller 116' then positions (e.g., rotates, translates, repositions) one or both of filters 102, 104, in step 206. Detector 108 then captures the image of wavefront 101, in step 208. In step 210, post processor 112 receives data from detector 108 and processes the data to reverse effects induced by filters 102, 104, to form final image 114 with user-selected imaging properties (e.g., depth of field, reduced aberrations, anti-aliasing).

Please amend paragraph **[0063]** as follows:

[0063] FIG. 7 shows one phase form ~~202~~302 of wavefront filters 102, 104 that may be used in optical system 100. Phase form ~~202~~302 includes a body ~~204~~304 of optical material having variations in thickness that induces phase change on wavefront 101. In one embodiment, form 302 implements a cubic phase function given by:

$$P(x,y) = \alpha x^3 + \beta y^3 + \delta x^2 y + \gamma xy^2 \qquad \text{(Eq. 5)}$$

where P(x,y) represents the phase function of filters 102, 104 as a function of spatial coordinates (x,y), where (x,y) is the displacement location of form ~~202~~302 from optical axis 103 (e.g., in FIG. 7 only axis x is shown). The constants α, β, δ, and γ are chosen according to the particular characteristics desired for optical system 100. For example, with $\alpha=\beta$, and $\delta=\gamma=0$, a rectangularly separable optical filter is formed. This leads to rectangularly separable processing within ~~digital signal~~post processor 112 in controlling depth of field and aberrations.

Please amend paragraph **[0064]** as follows:

[0064] Another phase function for form ~~202~~302 provides an MTF that is circularly symmetric. The wavefront phase of the optical filter can be written in polar coordinates as:

$$P(r,\theta)= \alpha f(r) \cos(n\theta) \qquad \text{(Eq. 6)}$$

where f(r) is a function dependent upon radial position r from a center of the phase function and θ is angular position about the center. By way of example, one phase function $P(r,\theta)$ is $\alpha r^3 \cos(3\theta)$, where f(r) is r^3 and n is 3 (which also corresponds to Eq. 5 with the constants chosen as $\alpha = \beta$, $\delta = \gamma = -3\alpha$). The magnitude of the constant α determines the amount of phase change implemented by filter(s) 102, 104, thus providing the selected imaging properties (e.g., depth of field, aberration-tolerance, or anti-aliasing).

Please amend paragraph **[0067]** as follows:

[0067] Other general phase forms may be described in polar coordinates, such as:

$P(r,\theta) = \cos(n\theta)\ A(r,\theta) + B(r)$ (Eq. 9)

where A(r, θ) and B(r) are functions of the radius (from optical axis 103) and θ, and cos(nθ) provides a non-rotationally symmetric rotational variation in the phase. The second term describes the general case, including displacement. For example, by fabricating the filter described by Eq. 6 onto the surface of a lens (e.g., form ~~202, FIG. 6~~302, FIG. 7), A(r, θ) is equal to [[a]]$\alpha r^3\cos(3\theta)$ and B(r) is equal to φr^2, where φ describes the power of the lens.

Please amend paragraph **[0072]** as follows:

[0072] FIG. 8 shows one optical system 400 similar to optical system 100 of FIGS. 3 and 4, with optics 406, a first aspherical optical wavefront filter 402, a second aspherical optical wavefront filter 404, a non-linear analog detector 408 and post processor 412, as well as automatic motor and controller 416. Wavefront 403 is formed from electromagnetic radiation 52 from object 50 and is focused by optics 406 through wavefront filters 402, 404 and to analog detector 408. Automatic motor and controller 416 rotates one or more of wavefront filters 402, 404 to effect mechanical adjustment of the wavefront phase. However, because of the non-linearity of analog detector 408 – in that detector 408 has a non-linear response to the intensity of wavefront ~~52~~403 - post processor 412 cannot perform the function of removing wavefront coding or spatial blur induced by wavefront filters 402, 404 to produce a sharp and in-focus final image 414. For non-linear analog detectors 408, such [[a]]as photographic film, the exposure curve is generally known or can be measured. Thus, the images detected by analog detector 408, representative of wavefront ~~402~~403, may be linearized. Non-linear analog detector 408 is thus digitally scanned to generate a representation 418 of the image. The scanned representation 418 is then linearized to form a linearized image 420. Post processor 412 (e.g., a digital filter) processes linearized image 420 (in much the same way as post processor 112 processes an image~~-420~~ to remove effects of wavefront filters 102, 104)~~,~~ to increase depth of field (depth of focus) in final image 414.